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An Experimental Study of the Effect of Private Information in the Coase Theorem

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Abstract

We investigate, in an experimental setting, the effect of private information on the Coase theorem's predictions of efficiency and allocative neutrality. For a two-person bargaining game, we find significantly more inefficiency and allocative bias in the case of private information compared with the case of complete information. We also find substantial bargaining breakdown, which is not predicted by the Coase theorem. For the case of private information, we reject the Coase theorem in favor of the alternative of a generalized version of the Myerson–Satterthwaite theorem, which predicts inefficiency, allocative bias in the direction of the disagreement point, and some bargaining breakdown.

Keywords: Coase theorem, Myerson-Satterthwaite theorem, two-person bargaining, private information, incomplete information, bargaining breakdown, cooperative and non-cooperative game theory

JEL Classification: C78, C92, D82

1. Introduction

In this paper we experimentally study the effect of private (incomplete) information on the Coase theorem. We find, for a specific two-person bargaining game, that the Coase theorem's predictive performance falls off substantially when we move from complete to private information.[1] For the case of private information, we test the Coase theorem against the alternative of a generalized version of the Myerson–Satterthwaite theorem.[2] In this test, we reject the Coase theorem in favor of the generalized Myerson–Satterthwaite theorem. We also find significant subject pool differences, but these do not affect the main conclusions.

As it is usually stated, the Coase theorem predicts (A) an efficient amount of harm (efficiency), and (B) an amount of harm which is not biased in favor of the holder of property rights (allocative neutrality). An immediate consequence of (A) is the third prediction, (C) no bargaining breakdown. The generalized Myerson–Satterthwaite theorem makes three contrasting predictions: (A') inefficiency (B') systematic bias in the amount of harm in favor of the rights holder (allocative non-neutrality, or bias); and (C') some bargaining breakdown.

There have been few empirical or experimental studies of the Coase theorem, assessing its predictive performance with and without private information, and to our knowledge none testing the predictions of Coase theorem against those of Myerson–Satterthwaite theorem. In one of the earliest and most interesting experimental studies of the Coase theorem, Hoffman and Spitzer (1985) found very high efficiencies with and without private information, and little difference between the two information environments. This finding differs from ours, of a substantial impact of private information in lowering efficiency.[3]

Hoffman and Spitzer provide an example of policy recommendation based on the Coase theorem and their evidence in support of the theorem. They write: "The almost complete dominance of Pareto optimal outcomes in our two-person experiment suggests that, if there is only one homeowner, a court may choose between [the polluter's right and the victim's right] ... with confidence that the parties will bargain to an efficient outcome. Hence, injunctive entitlements have appeal in two-party situations" (Hoffman and Spitzer, 1985, p. 97).

In contrast, the results of our experiment suggest more caution in basing policy recommendations on the Coase theorem, when there is private information. Adding to this caution, we conjecture that in cases of bargaining over actual environmental harms, where the structure of information and the payoff functions are more complicated, the amounts of harm are more than one-dimensional, and the number of bargainers more than two—that in such realistic cases the impact of private information may decrease the efficiencies below what we observed in our experiment for the incomplete information treatment.

The results of the paper can be viewed from another perspective as well: a comparison of approaches of cooperative and non-cooperative game theory. The Coase theorem shares the approach of cooperative game theory in several ways: the information structure and the institutional process of reaching a decision are both unmodeled. Instead, the characteristics of the solution concepts are built in "axiomatically" or by assumption.[4] As we shall see, for the bargaining game studied in this paper, the core, the Nash bargaining solution, and the von Neumann—Morgenstern bargaining set make the same three predictions made by the Coase theorem. And as with the Coase theorem, while cooperative game theory has often been developed with tacit or explicit assumptions of complete information, its solution concepts have sometimes been applied to situations with private information. For example, the First Welfare Theorem is often stated: "The competitive equilibrium is in the core," and this implication is often used to predict that market processes will tend toward efficiency, even when some information is private.

The obvious question to ask of this approach in cooperative game theory is how well do its predictions fare when there is private information, the important case for policy development. This question is sharpened by the contrasts between approaches and predictions in non-cooperative game theory.

In non-cooperative game theory the information structure and the institutional process are explicitly modeled. The information structure is precisely specified and the institutional process is explicitly defined in the extensive form of the game (or by specific rules of the game, as we do in the experiment). The solution concepts, such as a Bayesian equilibrium, often, but not always, imply inefficiency. But solution concepts in non-cooperative game theory also often imply multiple equilibria; there may be coordination problems in selecting an equilibrium; and often discovering an equilibrium requires complicated analysis. The same question arises: how well does the approach in non-cooperative game theory predict for actual decision problems?

While the differences in approach between cooperative and non-cooperative game theory can be clarified by theoretical analysis, empirical investigation is needed to assess predictive performance. It is difficult to estimate actual efficiencies econometrically, when the underlying values and costs are private information. But in experiments, the experimenter can "induce" values and costs, facilitating their estimation. Perhaps because of this advantage, there have been an increasing number of experimental studies on the predictive performance of cooperative and non-cooperative game theoretic solution concepts.

Under some experimental conditions, solution concepts from cooperative game theory have predicted very well, with and without complete information. When there is private information the core has predicted well for experimental markets, double auctions, and committee voting (Ordeshook, 1986, pp. 370–376). Also in a bargaining experiment with private information Roth and Malouf (1979) found the Nash bargaining solution predicted better in an incomplete information environment than in a complete information environment (Holt and Davis, 1993, p. 251). Non-cooperative solution concepts have also predicted well, under some experimental conditions.

The results of our paper suggest that for the specific conditions of our experiment, the non-cooperative approach as exemplified by the Myerson–Satterthwaite theorem are better models of behavior than the core, the Nash solution, or the von Neumann–Morgenstern bargaining set.

The paper is organized as follows. In Section 2, we construct the bargaining game of the experiment. In Section 3 we discuss two assignments of rights—polluter's rights and victim's rights—and show how both reduce to the bargaining game of the experiment. In Section 4, we identify predictions for this game from Coase, cooperative game theory, and the competitive equilibrium. In Section 5, we identify contrasting predictions from a generalized version of the Myerson–Satterthwaite theorem. In Section 6, we report the results of experiments run on the bargaining game.

2. Design of the experiment

In this section, we do three things. First, we list our design goals. Second, we specify the bargaining game used. Third, we explain how the game was operationalized in our experiments.

2.1. Design goals

To facilitate comparison of the Coase theorem and the Myerson–Satterthwaite theorem, our main design consideration was to construct a bargaining game which fits the conditions of both theorems. More specifically, we incorporated the following design characteristics:

- Assignments of rights were defined in terms of a disagreement point, which is made known as common knowledge. This feature fits with the Myerson–Satterthwaite theorem and has been used in analyses of the Coase theorem (see Hurwicz, 1995). This design feature simplifies our comparison of the two theorems.
- Quasi-linear payoff functions. The generalized Myerson–Satterthwaite theorem (stated below) incorporates quasi-linear utility, and one of the sufficient conditions for the implication of allocative neutrality in the Coase theorem is quasi-linear utility (Hurwicz, 1995). We can't insure that induced utility will be the same as monetary payoffs in the experiment, but the use of quasi-linear payoffs works in the direction of quasi-linear utility.
- Free-form bargaining. We attempted to define a bargaining process which was as unstructured as possible. The Myerson–Satterthwaite theorem applies to virtually any two-person bargaining process, and in much of the literature on the Coase theorem the bargaining process is either explicitly free form (e.g., the Hoffman–Spitzer experiment) or unspecified (e.g., Coase's example of the farmer and the cattle-raiser (Coase, 1960)).
- Two-person bargaining. Much of the literature on the Coase theorem focuses on this simpler case, and two-person bargaining is a feature of the Myerson–Satterthwaite theorem.
- Strict control of information flows. We wanted to maintain a clear separation between complete and private (incomplete) information treatments. Private information is a condition of the Myerson–Satterthwaite theorem, and a blurring of this distinction, through face-to-face bargaining, may have been a source of the observed high efficiency in the Hoffman–Spitzer experiment.
- A divisible amount of harm. Much of the policy application is for a divisible amount of harm and most of the literature on the Coase theorem is for a divisible amount of harm. The Myerson–Satterthwaite theorem is only for an indivisible unit of a good (or harm) and to make our comparison, we derived in a theoretical paper (McKelvey and Page, 2000) a generalized version of the Myerson–Satterthwaite theorem to apply to a divisible harm.
- Low transaction costs. This is a requirement of the Coase theorem. Coase explicitly discussed transactions costs as an impediment to efficiency,[5] and the Coase theorem is considered to be valid only when transactions costs are zero. Consequently, in our experiments, we have tried to set up an environment where the transactions costs are minimized. It is sometimes argued that incomplete information is simply an environment in which the transactions costs are high. However, this equivalence is not correct, because unlike transaction costs, the inefficiencies and property rights biases due to incomplete information cannot be eliminated by policies designed to make it easier to bargain and negotiate, since these inefficiencies are a result of strategic behavior (unwillingness to reveal private information), which will persist in any game form, even when there are no costs to bargaining.
- Quadratic cost and benefit functions. Quadratic cost and/or benefit functions have been used previously in the literature on the Coase theorem. Coase, in his table and discussion of the rancher and farmer, uses a quadratic cost function for the farmer (1990, pp. 97–98); Turvey (p. 311, figure 1), Demsetz (p. 68, figure 1), and Mishan (p. 20, figure 2) have quadratic cost and benefit functions of pollution.

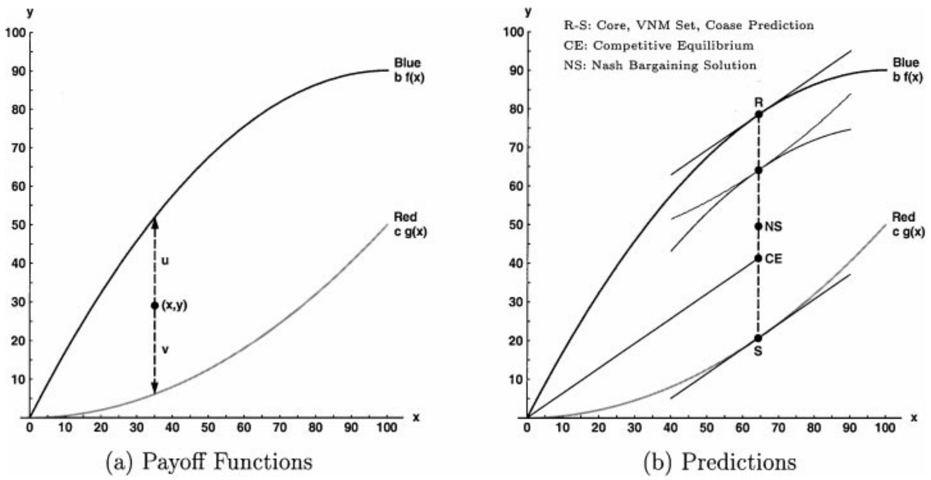

Figure 1. Sample payoff functions for $b = .9$, $c = .5$. The efficient x is at $x^* = 100b/(b + c) = 64$.

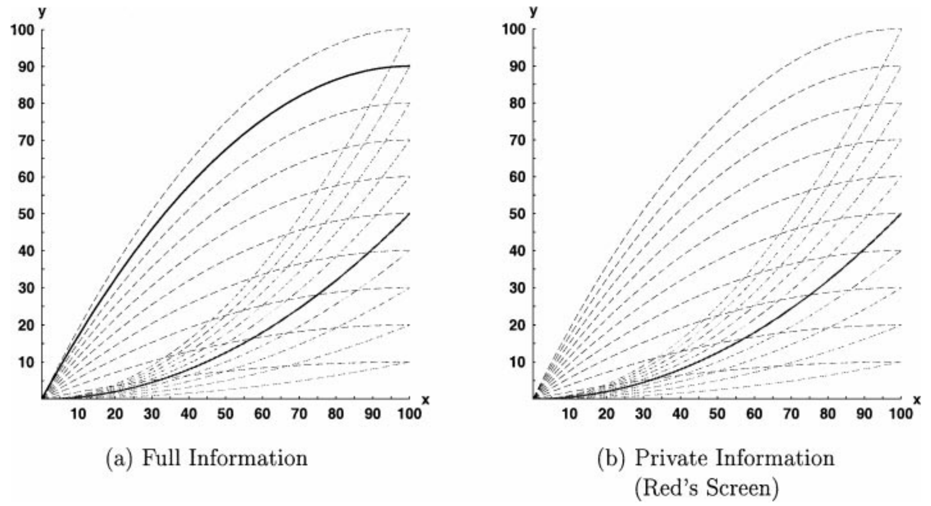

Figure 2. Sample computer display for $b = .9$, $c = .5$.

2.2. Specification of the game

The following bargaining game incorporates the above design goals. There are two players, "Blue" and "Red," who bargain over the location of a point in a square, $A = [0, 100] \times [0, 100]$. Define $f, g : [0, 100] \mapsto \Re$ by $f(x) = 2x - \frac{x^2}{100}$, and $g(x) = \frac{x^2}{100}$. If the two players agree on a particular point $(x, y) \in A$ then their payoffs are:

(1) $u(x, y; b) = bf(x) - y$ Blue player's payoff

(2) $v(x, y; c) = y - cg(x)$ Red player's payoff

(3) b, c Independent and uniform random variables,

$b \in \{0.1, 0.2, \ldots, 1.0\}$ each w.p. 0.1 and

$c \in \{0.1, 0.2, \ldots, 1.0\}$ each w.p. 0.1

(4) $(x, y) = (0, 0)$ Status quo, or disagreement point

where x and y are integers between 0 and 100.

The payoff functions are illustrated in figure 1(a) for the case where $b = .9$ and $c = .5$. In the experiment, Red and Blue either come to an agreement on a point (x, y) in the unit square or end up with (0,0) as the disagreement point. If (x, y) is the agreed-upon point, then Red's payoff v is the vertical distance of (x, y) above Red's curve $cg(x)$; Blue's payoff, u, is the vertical distance of (x, y) below Blue's curve $bf(x)$. If there is no agreement, (0, 0) is chosen, the distances are zero and $u = v = 0$.

2.3. *Operationalization*

The above game was set up to run over a computer network, with subjects only able to communicate with each other over the network. Table 1 shows the details of the experiments we ran. We ran four experiments on separate days (in May and June, 2000), using from 18 to 22 subjects in an experiment, and 82 subjects altogether (see column (2) of Table 1). Two experiments used California Institute of Technology (CIT) undergraduates, and two used Pasadena City College (PCC) students.[6] At the beginning of each experiment, half the subjects were randomly assigned the color Blue, and the other half Red. These assignments remained fixed during the entire experiment. The experiment consisted of 16 bargaining sessions. In each session, each Blue subject was randomly matched with a Red subject, giving rise to $\frac{n}{2}$ *matches* per session, where n was the number of subjects in the experiment. The first four sessions consisted of complete information matches, the next eight sessions consisted of incomplete information matches, and the final four sessions were complete

Table 1. Details of experiments.

Experiment	Subject pool (1)	Number of subjects (2)	Number of full info matches (3)	Number of private info matches (4)
1	*CIT*	18	72	72
2	*CIT*	24	96	96
3	*PCC*	22	94	88
4	*PCC*	18	72	72
Total		82	334	328

information matches. As shown in columns (3) and (4) of Table 1, this yielded a total of 334 two-person matches with complete information (168 for CIT and 166 PCC), [7] and 328 $(55 + 54)$ matches with private information (168 CIT and 160 PCC).

As mentioned above, we ran two treatments, one with complete (full) information and one with incomplete (private) information. In both of the treatments, subjects know, as common knowledge, the payoff functions, the pdf's of b and c, the disagreement point, and the domains of x and y. In the game with private information observations on b and c are not common knowledge. After the random variables are drawn, Blue learns b but not c, and Red learns c but not b and both subjects are informed publicly of this information structure. In the complete information game, both subjects learn both b and c as common knowledge.

In the experiment, each subject privately sees his/her own computer screen, which looks much like figure 2(a) when information is complete, and like figure 2(b) when information is incomplete. In both treatments, the subjects see all the possible payoff curves for each of the subjects as dotted lines of the appropriate color. For the complete information treatment, subjects see both their own true payoff curve and the true curve of the subject that they are matched with as highlighted solid curves of the appropriate color. So both subjects see the identical information on their screen. In the private information treatment, Red sees the true Red curve but not the true Blue curve highlighted, and Blue sees the true Blue curve but not the true Red curve highlighted (both are publicly told this). So the only difference between the two treatments is whether the true curve of the other subject is highlighted.

In the experiment the subjects can determine the approximate payoffs from any potential outcome $(x, y) \in A$ by moving their mouse to that point on the screen. A display on their computer screen gives their exact payoff from that point. This payoff is continually updated with the correct payoff as they move the mouse around the screen.

Each match of the experiment is run in continuous time over a finite time period (three minutes). When the match starts, a clock on each subject's screen constantly ticks off the seconds remaining. To make an offer, a subject clicks her mouse on a point, (x, y) on her screen. When an offer is made, a small token (colored disk) is simultaneously displayed on her screen and the screen of the subject she is matched with. Only one offer for each subject is valid at a time. The subject can revise her offer by making another offer. Current offers are shown as a solid disk of the same color as the subject that made it, and the preceding four offers are shown as colored circles. There are no restrictions on the order that subjects make offers, and no restriction on the number of offers that can be made by either subject. At any time, either subject can accept an offer, (x, y) made by their partner by clicking on the token representing the other's current offer. In this case, (x, y) is the agreement point, and each gets a payment as defined above. If there is no agreement before the time runs out, the disagreement point (0, 0) is chosen by default, and both subjects get zero payoff.

In the experiment, the subjects are given no interpretations about their roles, the choice variables, or the payoff function. The subjects are just referred to as the Red and Blue subjects, x and y are just described as the horizontal and vertical coordinates on the computer screen, the curves on the screen are described only in terms of how they are used to compute payoffs, etc. In the instructions to the experiment there is no mention of "rights," "polluter," "victim," "utility parameter," or to Coase or Myerson–Satterthwaite. Even the words "bargaining game" are not used, to avoid their possible connotations, and the experiment is called more neutrally, "an experiment in decision making."

We will call the above bargaining game the "uninterpreted experiment."

3. Assignment of rights

The above experiment can be interpreted with two differing assignments of rights.

We consider an example where x is the amount of an environmental harm, say smoke. The victim bears a cost of $cg(x)$ from x, the level of smoke emitted by the polluter. The polluter benefits $bf(x)$ from a level x of smoke.

- *Victim's rights.* Here the victim has the right to choose the level of pollution. Since $cg(x)$ is minimized at 0, he will choose clean air, or $x = 0$. The polluter could offer a monetary transfer y to the victim in exchange for the victim allowing some positive amount of pollution. But since the victim has the right to choose x, the status quo, or default outcome that will occur if there is no joint agreement is $(x, y) = (0, 0)$.

  With this assignment of rights equations (1) to (4) have the following interpretation: (1) $u(x, y; b) = bf(x) - y$ is the payoff to the polluter, (2) $v(x, y, ; c) = y - cg(x)$ is the payoff to the victim, (3) b and c are the polluter and victim's types, respectively, and (4) $(x, y) = (0, 0)$ is the disagreement point as determined by the assignment of rights to the victim.

- *Polluter's rights.* In this second assignment of rights the polluter has the right to choose x. Since $bf(x)$ is maximized at $x = 100$, she will choose to emit 100 units of smoke. The victim could offer a monetary payment to the polluter to cut back pollution. But since the polluter has the right to choose x, the status quo, or default outcome that will occur if there is no joint agreement, is $(x, y) = (100, 0)$.

The two assignments of rights are quite different. Under victim's rights, disagreement leads to no pollution, but under polluter's rights disagreement leads to 100 units of pollution. Nonetheless, the second assignment of rights also reduces to the same uninterpreted game (1)—(4). To see this write $t = -y$, as the transfer from the victim to the polluter, $z = 100 - x$, as the amount of abatement. Then since $f(x) = 100 - g(z)$ and $g(x) = 100 - f(z)$, we can rewrite the payoff to the polluter as

$$u(x, y; b) = bf(x) - y = t - bg(z) + 100b = v(z, t; b) + 100b$$

and the payoff to the victim as

$$v(x, y; c) = y - cg(x) = cf(z) - t - 100c = u(z, t; c) - 100c$$

Without changing the analysis, we can normalize payoffs so both agents have a utility of zero at the new status quo, $(x, y) = (100, 0)$. This can be accomplished by charging a tax of $bf(100) = 100b$ to the polluter, and giving a subsidy of $cg(100) = 100c$ to the victim—i.e., eliminating the last term in each of the above equations.

Now we get: (1′) $u(z, t; c) = cf(z) - t$ is the payoff to the victim, (2′) $v(z, t; b) = t - bg(z)$ is the payoff to the polluter, (3′) c and b are the victim and the polluter's types, respectively, and (4) $(z, t) = (0, 0)$ is the disagreement point as determined by the assignment of rights to the polluter.

But now we simply note that if we let z take the role of x, t take the role of y, b take the role of c, and c take the role of b, we that (1′) to (4′) above are identical to (1) to (4), where the blue subject is now the victim, and the red subject is now the polluter. This equivalence means that it is not necessary to run two different treatments, where half of the experimental bargaining sessions have victim's rights, and half have polluter's rights, because when we run the experiments blind (stripped of the interpretive words in pollute, "victim," "rights", etc.), we would use the same instructions and game form for both rights assignments. Because the two assignments of rights reduce to the same uninterpreted game, we are able to test the Coase theorem with just the one experimental game.

The bargaining game can also be given an interpretation corresponding to the usual interpretation of the Myerson–Satterthwaite theorem. Blue is the buyer, $bf(x)$ is the benefit to the buyer from buying x amount of the good, Red is the seller, $cg(x)$ is the cost of producing and selling x, the rights are assigned so that the seller initially owns the good, and y is the payment from the buyer to the seller.

4. Predictions from Coase, cooperative game theory, and the competitive equilibrium

The Coase theorem predicts an efficient amount of x, and this amount is easy to calculate. To find the efficient amount for a particular realization of b and c, maximize the social surplus $u + v = bf(x) - cg(x) = b(2x - x^2/100) - \frac{cx^2}{100}$, over x, getting the efficient amount of x to be $x^* = \frac{100b}{b+c}$. In figure 1(b) the efficient x is the value of x which maximizes the gap between the Red and Blue curves. In the figure, all the points on the line segment RS are efficient. To allow for error and Coase's prediction to be approximate rather than exact, define the **bias**, $r = x - x^*$, to be the residual difference between the actual amount of x chosen in a match with utility-relevant parameters b and c, and the efficient amount, x^*. So

$$x = x^* + r = \frac{100b}{b+c} + r.$$

For Coase's prediction of efficiency to be exact we must have $r = 0$ for every b and c. For Coase's prediction of efficiency to be approximately true we must have $E(r)$ and $var(r)$ to be "small." For a Coasian prediction of approximate efficiency to extend from the case of complete information to private information with little difference in predictive accuracy we must have $E(r)$ and $var(r)$ about the same with and without complete information.

Coase's prediction of allocative neutrality can be interpreted as a claim that $E(r) = 0$ even if $var(x) > 0$. To see this consider what would happen if $E(r) \neq 0$. For example, if $E(r) < 0$, then with the interpretation of victim's rights x is the amount of pollution and $E(r) < 0$ implies that the amount of pollution is systematically less than the efficient amount. With the interpretation of polluter's rights x is the amount of abatement and $E(x) < 0$ implies that the amount of abatement is systematically less than the efficient amount, and hence, the amount of pollution is systematically more than the efficient amount of pollution. But then the amount of pollution varies systematically with the assignment of rights, contrary to Coase's claim of allocative neutrality.

We define a bargaining breakdown as occurring whenever the actual $x = 0$ but the efficient x is positive. In the experiment $b > 0$ and $c > 0$, so the efficient x is always positive. We conclude that whenever the observed $x = 0$ we have a case of bargaining breakdown. Thus an implication of Coase's prediction of efficiency is that there will be no observed breakdowns (no cases of $x = 0$). More practically, a prediction of approximate efficiency (where $E(r)$ and $var(r)$ are both small) is that there will be few cases of bargaining breakdown.[8]

For future reference we gather these Coasian predictions:

(A) For all b and c, $r = 0$ (full efficiency)
$E(r)$ and $var(r)$ are both "small" (approximate efficiency)

(B) $E(r) = 0$ (allocative neutrality)

(C) For all b and c, $Pr[x = 0] = 0$ (no bargaining breakdown)

For all b and c, $Pr[x = 0]$ is "small" (breakdown rare).

These predictions also follow from other solution concepts which predict efficiency. These include the core, a competitive equilibrium, the von Neumann–Morgenstern bargaining set, and the Nash bargaining solution because they all agree with the Coase theorem's claim of efficiency. These solution concepts are illustrated in figure 1(b). Assuming that the bargainers attempt to maximize their expected payoff we can interpret payoffs as utilities, and in the figure, with victim's rights, $b(2x - x^2/100)$ is not only the polluter's benefit from pollution x, but $y = b(2x - x^2/100)$ is also an indifference curve for Blue, the locus of points (x, y) where $u = 0$; similarly $y = cx^2/100$ is Red's indifference curve where $v = 0$. With quasi-linear utility, Blue's indifference curves are vertical translations of $bf(x)$ and similarly for Red. The contract curve is a vertical line and it goes through the maximum gap between $bf(x)$ and $cg(x)$. The segment *RS* is that part of the contract curve which also satisfies individual rationality ex post (IR). Thus, for the two-person game, *RS* is the core, and the von Neumann–Morgenstern bargaining set is also *RS*. Coase also predicts bargaining will lead to an allocation which is both efficient and satisfy IR, in other words also in *RS*. The competitive equilibrium predicts the point *CE* where a line, through (0, 0) and parallel to the tangent at S, intersects *RS*. The Nash bargaining solution predicts the point *NS*, which provides an equal sharing of the maximum social surplus over the disagreement point.

5. Predictions from the generalized Myerson—Satterthwaite theorem

For any b, c, and x the social surplus is $u + v = bf(x) - cg(x) = 2bx - (b + c)x^2/100$. Recall that the social surplus is maximized at $x^* = \frac{100b}{b+c}$. Thus the maximum social surplus for b and c is

$$2b\left(\frac{100b}{b+c}\right) - \frac{b+c}{100}\left(\frac{100b}{b+c}\right)^2 = \frac{100b^2}{b+c} \tag{1}$$

We define the **ex post efficiency** of a given x to be the social surplus divided by the social surplus of the efficient allocation. So the ex post efficiency of x, given b and c, is $e(x; b, c) = \frac{b+c}{100b^2}(2bx - (b+c)x^2/100)$. The **expected efficiency** of the allocation rule x is defined as $E[e(x(b, c); b, c)] = E[\frac{b+c}{100b^2}(2bx - (b+c)x^2/100)]$.

The Myerson–Satterthwaite theorem [Myerson–Satterthwaite, 1983] applies to an indivisible good. We have derived (McKelvey and Page, 1996) a generalized version of the theorem which applies to a divisible amount of a good (or harm) and to the bargaining problem of the experiment. The result is:

Proposition (*Generalization of Myerson–Satterthwaite*)**.** *Assume individual utility functions and information are as in* (1)–(4)*. And define*, *as before the bias* $r = r(b, c) = x(b, c) - 100b/(b+c)$. *Then any incentive compatible direct mechanism* $(x(b, c), y(b, c))$ *satisfying individual rationality (ex ante or ex post) also satisfies*:

(A') $E[e(x; b, c)] < 1$ (*inefficiency*)

(B') $E(r) < 0$ (*allocative bias*)

For a finite approximation corresponding to the experiment that we ran, we calculated Bayesian equilibria to the game of the Proposition. We found multiple equilibria to the game, and suspect that there are many more equilibria than we computed. In one Bayesian equilibrium we found bargaining breakdowns five percent of the time, in another we found breakdowns ten percent of the time, and in a third we found breakdowns 14 percent of the time.[9] Since we know that at least some Bayesian equilibria have bargaining breakdowns, and we have no theory ruling out Bayesian equilibria with breakdowns, we make a third prediction:

(C') $Pr[x = 0] > 0$ (Some bargaining breakdown)

The three predictions of the Coase theorem (A), (B) and (C) can be tested in treatments with and without complete information, and in doing so the effect of private information can be studied. Here information is the treatment variable.

For the treatment with private information the conflicting predictions of Coase—(A), (B), and (C)—versus Myerson and Satterthwaite—(A'), (B') and (C')—can each be evaluated by considering the prediction of the Coase theorem as the null hypothesis, and testing whether we can reject it in favor of the alternative, as specified by the generalized Myerson–Satterthwaite theorem.

6. Experimental results

We now analyze the experimental data in light of the predictions made by the Coase and Myerson–Satterthwaite theorem.

Let n be the total number of observations (matches), and let the k subscript denote the values of the corresponding variables in the kth match. For match k, the *efficiency* is defined, as in the previous section, by

$$e_k = \frac{b_k + c_k}{100b_k^2}\left(2b_k x_k - \frac{b_k + c_k}{100}x_k^2\right),$$

the *bias* is defined as the residual of x from the efficient point, x^*,

$$r_k = x_k - x_k^* = x_k - \frac{100b_k}{b_k + c_k},$$

and we define a dummy variable for *bargaining breakdown*, $B_k = 1$ if the kth match ends in breakdown and $B_k = 0$ otherwise.

Table 2 presents data evaluating the three predictions of the Coase theorem under the full and private information conditions. Column (1) gives the Coase prediction for average efficiency, $\bar{e} = \frac{1}{n}\sum_k e_k$, the average bias, $\bar{r} = \frac{1}{n}\sum_k r_k$, and the proportion of breakdowns, $\frac{1}{n}\sum_k B_k$. Columns (2) and (3) of this table present the experimental data for the complete (Full) and incomplete (Priv) information treatments, respectively. Since we find some significant differences between the CIT and PCC subject pools, we present the results broken down by subject pool.

It is evident from column (4) of Table 2 that there are substantial differences between the two information treatments, with the results being systematically further from the Coase

Table 2. Coase Theorem's predictions compared with experimental outcomes, for the two treatments.

			Treatment			
	Pool	Coase Prediction (1)	Full (2)	Priv (3)	Diff (4)	t (5)
(A) Efficiency	CIT		.930	.759	.171	5.14**
	PCC	1.00	.758	.534	.224	1.98*
	ALL		.844	.648	.195	3.34**
(B) Bias	CIT		−4.58	−16.40	11.82	7.08**
	PCC	0	−8.23	−12.11	3.88	1.69*
	ALL		−6.39	−14.31	7.91	5.57**
(C) Breakdowns	CIT		.060	.173	.113	3.28**
	PCC	0	.187	.263	.076	1.64
	ALL		.123	.216	.094	3.24**

* indicates significant at level .05, and ** indicates significant at level .01.

predictions in the case of private information than in the complete information treatment. The average efficiency is greater by .195 under complete information than incomplete. There is a greater bias towards the status quo (by 7.9 units) under private information, and the percent bargaining breakdowns under incomplete information exceeds that of incomplete information 9.4 percentage points. The directions of the differences for each of the three predictions are the same within each subject pool. However, there is overall lower efficiency in the PCC subject pool than in the CIT subject pool,[10] and the strength of the other differences is less in the PCC subject pool than in the CIT subject pool, leading to higher p values for significance tests. Using a one tailed t test, reported in column (5), significance at the .05 level is attained in all cases except for bargaining breakdown in the PCC pool (where the t value of -1.642 is just shy of the required critical value of -1.645).

So our first conclusion is that for all three criteria, we see significant differences between the two treatments, which would not be accounted for by the predictions of the Coase Theorem.

As we discussed in the previous section, all three of the predictions of the Coase theorem are related to the distribution of the bias, r_k. If the mean and variance of the r_k are both small, then efficiency will be close to one, bias will be close to zero, and bargaining breakdown will be rare. If the average observed bias is small (even with a large variance), there will be approximate allocative neutrality.

Table 3 shows the details of the distribution of the bias term, r, in the two treatments, with columns (1) and (2) giving the number of observations, columns (3) and (4) giving the mean bias, and columns (5) and (6) the standard deviation of the bias, for each corresponding subset of the data. The last three columns of Table 3 present statistical tests for differences in the distributions between the complete (full) and incomplete (private) information treatments. Column (7) is a t test for the difference in means, (8) an F test for the difference in variances, and (9) a Kolmogorov–Smirnov test for the difference in cumulative distributions. All tests are one tailed. Looking at the data for all observations, presented in the top portion of the table, we see that in addition to the significant differences in the mean, noted above, there is significantly more variance in the CIT data, but not in the

Table 3. Distribution of bias (r) for full and private information treatments. Top rows of table represents all data, bottom is data where agreement was reached.

		n		Mean		StdDev				
Data	Pool	Full (1)	Priv (2)	Full (3)	Priv (4)	Full (5)	Priv (6)	t (7)	F (8)	KS (9)
ALL	CIT	168	168	−4.58	−16.40	11.9	18.1	7.08**	2.30**	.506**
	PCC	166	160	−8.23	−12.11	20.7	20.8	1.69*	1.01	.247**
	ALL	334	328	−6.39	−14.31	16.9	19.6	5.57**	1.34**	.361**
Agreement	CIT	158	139	−1.93	−11.51	4.9	14.2	7.94**	8.24**	.485**
	PLC	135	118	−1.20	−4.12	11.4	15.3	1.73*	1.82**	.262**
	ALL	293	257	−1.59	−8.12	8.5	15.2	6.32**	3.16**	.364**

* indicates significant at level .05, and ** indicates significant at level .01.

PCC data. To see whether the bias towards the status quo is due to bargaining breakdown, the bottom portion of Table 3 (labeled "Agreement") reports the distribution for only those observations in which agreement was reached. Here we see that there is still a significant difference between the two information treatments, with a greater bias towards the status quo and higher variance in the incomplete information treatment. All differences are significant. However, as before the magnitude and level of significance of the differences in the PCC pool is less than that for the CIT pool.

Figures 3–5 shows histograms of the bias term r for the two treatments. In these figures, the cases of bargaining breakdown are shown as unshaded. In the treatment of complete information (figure 3 (a)) the deviations are roughly symmetric around zero, as predicted by (A) and (B) of the Coase theorem. But for the treatment with private information (figure 3 (b)), the bias r tends to be negative, as predicted by the Myerson–Satterthwaite theorem and contrary to the Coase theorem.

Clearly the observed allocative bias and inefficiency for the incomplete information treatment occurs even when the cases of bargaining breakdown are excluded from the analysis. These bargaining breakdowns and allocative bias are anomalies for the Coase theorem, but predicted by the Myerson–Satterthwaite theorem.

For the private information treatment, we can test the Coase Theorem's prediction of allocative neutrality against the generalized Myerson–Satterthwaite theorem's prediction of bias toward the disagreement point. We treat the Coase theorem as the null hypothesis and the Myerson–Satterthwaite theorem as the alternative, and use one tailed tests of a simple hypothesis against a composite alternative for this test. Letting $E_p(r)$ be the expected value of r in the private information treatment, the test is

$$H_0 : E_p(r) = 0 \text{ (Coase prediction of allocative neutrality)}$$

$$H_1 : E_p(r) < 0 \text{ (Myerson–Satterthwaite alternative of bias)}$$

For this we used a one-tail t test; $t = -13.2$, $df = 328$, p value $< .0001$. We reject the Coase hypothesis in favor of the Myerson–Satterthwaite alternative. Within each subject pool, we can similarly reject the null Hypothesis ($t = 11.7$ for CIT and $t = 7.36$ for PCC). Considering only the observations in which agreement is reached, we can also reject the null hypothesis in the above test (with t values of 9.56, 2.92, 8.56 for CIT, PCC, and ALL, respectively).

Table 4 summarizes the predictions versus the actual data for the private information treatment. The magnitude of the differences from the Coase predictions is substantial. For the CIT subject pool, efficiency is higher and there are fewer bargaining breakdowns, yet the bias is greater in magnitude. This suggests that more analytically inclined or sophisticated subjects will not get rid of the allocative bias.

The magnitude of the bias can be roughly illustrated as follows: With an average bias on the order of 15 units, when the efficient level of pollution is 50 we could easily see 65 units of pollution with polluter's rights and only 35 with victim's rights—a result strongly at odds with Coase's claim that the allocation of rights has no effect on the level of pollution.

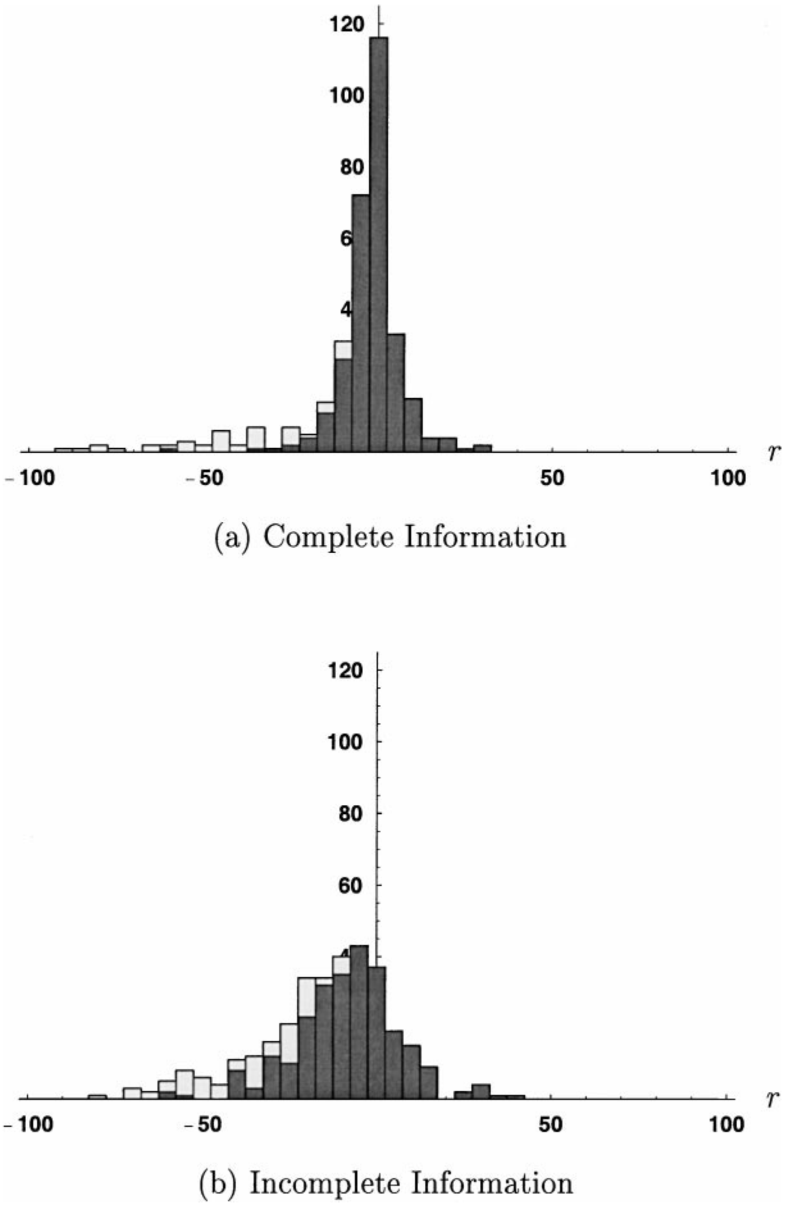

Figure 3. Histograms of bias (r) for pooled (CIT and PCC) experiments (unshaded portion results from bargaining breakdown).

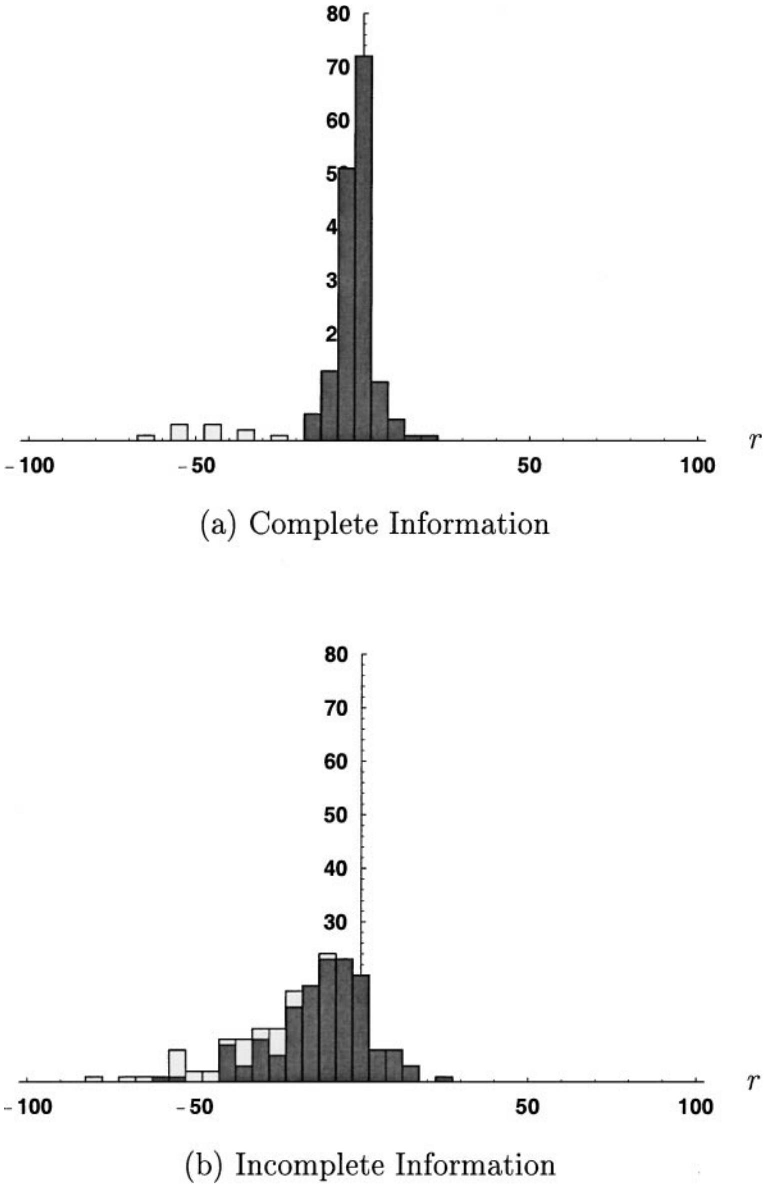

Figure 4. Histograms of bias (r) for CIT experiments (unshaded portion results from bargaining breakdown).

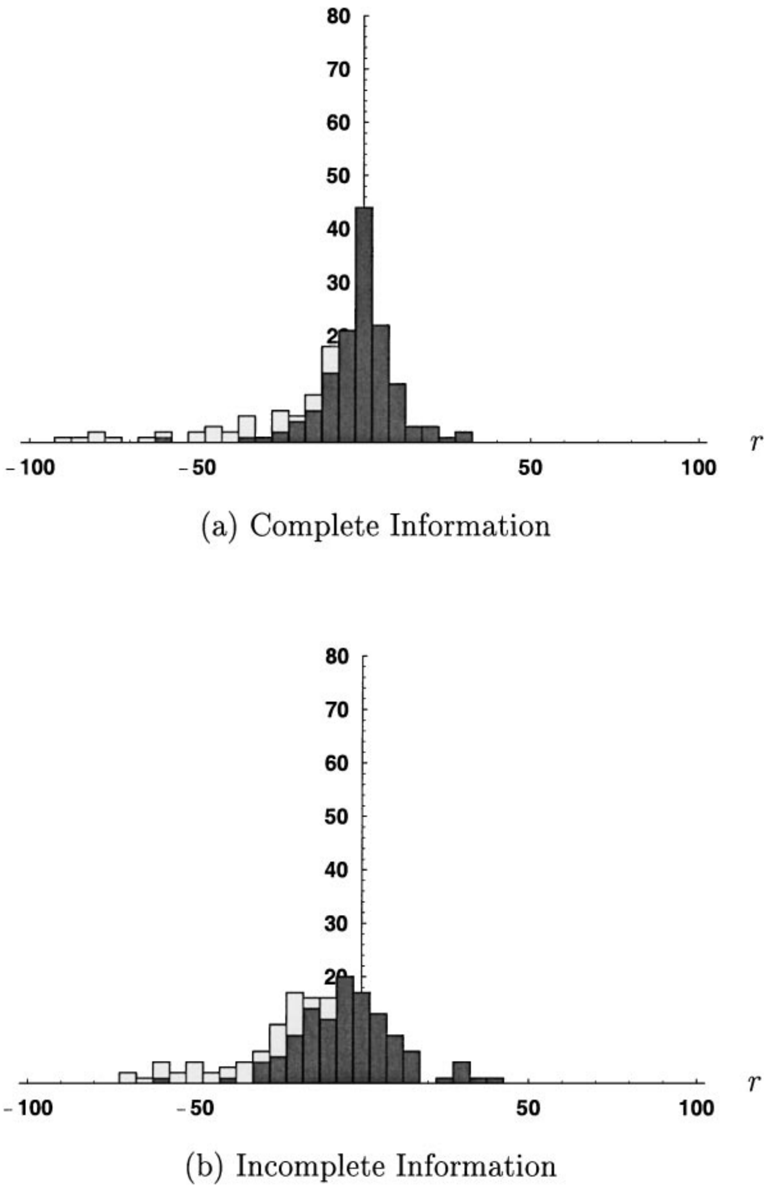

Figure 5. Histograms of bias (r) for PCC experiments (unshaded portion results from bargaining breakdown).

Table 4. Predictions versus observed data for private information treatment.

	Prediction		Observed		
	Coase	M-S	CIT	PCC	ALL
(A) Efficiency	1.00	<1.00	.759	.534	.648
(B) Bias	0	<0	-16.40	-12.11	-14.31
(C) Breakdown	0	>0	.173	.263	.216

6.1 The bargaining process

A more detailed inspection of the sequences of offers and counter-offers suggests that the bargaining process, when there is complete information differs substantially from the process with private information. In most of the bargaining sessions with complete information, the offers and counter-offers went quickly to the efficient level of x and then bargaining continued over the transfer payment y (in the complete information treatments the bargaining looked a lot like a divide-the-dollar game). In many cases an equal or close-to-equal split was offered and then accepted (with efficiency close to 1). But occasionally one subject (or both subjects) would hold out for a larger share of the maximum social surplus, and sometimes this would lead to bargaining breakdown. It appears that most of the inefficiency in the complete information treatments comes from this type of bargaining breakdown (in which a symmetric game of divide the dollar becomes a game of chicken). It appears that even with occasional bargaining breakdown, the Nash bargaining solution predicted well, when there was complete information, because close to equal splits of the maximum social surplus were frequently observed.

The process of offers and counter-offers looks different in the treatments with private information. Here the game does not look like a divide-the-dollar game. Not only do the subjects not know where the maximum social surplus is, they even have considerable trouble discovering values of x which satisfy individual rationality for both subjects (it appears that some of the breakdowns arise because they fail to find, with any confidence, values of x which are mutually individually rational, especially when b is low and c high).

In treatments with private information the observed pattern of bargaining is consistent with the usual interpretation of bargaining over a divisible good—the buyer systematically understates his value and begins by asking for large amounts of x at low prices; the seller systematically overstates her cost and begins by offering large amounts of x at high prices. Gradually both subjects soften their demands. The buyer raises his bid price and also decreases the amount of x offered to be bought. Correspondingly, the seller lowers the asking price and also lowers the amount of x offered to be sold. This systematic lowering of the x offers is sensible, since the subjects know as common knowledge that the marginal benefits of the good to the buyer increase as x decreases and the marginal costs to the seller decrease as x decreases.

There are many fewer equal splits when there is private information, which is not surprising because the subjects have no way of knowing what would be an equal split. Thus, it appears that bargaining with private information follows a quite different dynamic; the pattern for both subjects of initially high and then falling offers of x is not observed when there is complete information.

6.2 Alternative explanations

We now consider two possible alternative explanations for the differences we see in the two treatments.

Distribution of b and c. The values of b and c are generated in the experiment by a random number generator. If the realized distributions were significantly different, and there is a relation between these variables and the bias, r, then this could potentially provide an alternative explanation for our results.

We test whether there are any differences in realized sample distributions of b and c between treatments using a (two tailed) t-test for difference in the means, and a chi squared test for independence of the distributions across treatments. None of the chi squared tests show any significant difference. The lowest p value (at 9 degrees of freedom) is $p = .10$. But we do find significant difference (at the .05 level) in the means of b for PCC and ALL (with t values of 2.32 and 2.08, respectively. To see whether how these differences might affect our results, we also investigated the distribution of the efficient value of x^*, which is the main explanatory variable in our analysis. We computed a (two tailed) t test for difference in means, and the Kolmogorov–Smirnov statistic for significant difference in the distributions between the two treatments.[11] None of these tests are significant at the .05 level, and we conclude that the differences in the distribution of b and c do not translate into significant differences (at the .05 level) in the distribution of x^*.

Even though the differences are not significant at the .05 level, we consider the effect the differences would have on our reported results: For each subject pool (CIT, PCC, ALL) and each information condition (FULL, PRIV) we ran regressions of the form $r = \alpha + \beta x^*$, and found that in all cases, the $\hat{\beta} < 0$. It follows that the differences that exist in the distributions between the full and private information treatment lead to *under* estimates of the difference in the bias. We conclude that any effects caused by random differences in the distributions of b and c make it harder to find significant differences in the bias between the two treatments, and hence discard this factor as a possible explanation for the observed differences.

Truncation of policy space at $x = 100$. In our experiment, the outcome space was truncated at $x = 100$. Therefore, for draws of b and c which lead to x^* equal or close to this bound, it is impossible for the subjects to exhibit positive bias. In fact, for any draw of b and c for which x^* is strictly greater than 50, the set of points that are Pareto preferred to the status quo, (0,0), includes points outside of the feasible set. Hence, if the subjects were to choose from a uniform distribution over the set of points Pareto preferred to the status quo, but which also satisfy the constraint that $x \leq 100$, then one would expect to see a negative bias.

To check whether our results are being generated by the truncation of the policy space, we reanalyze the data, considering only those observations in which $x^* \leq 50$. Tables 5 and 6 are analogous to Tables 2 and 3, respectively. Table 5 shows that the direction of the differences is the same for all three predictions, and for both subject pools as well as the full sample. Further, in the reduced sample, all of the differences are significant at the .05 level.

Table 5. Coase Theorem's predictions compared with experimental outcomes, for the two treatments (only observations with $x^* \leq 50$).

	Pool	Predicted (1)	Mean Full (2)	Mean Priv (3)	Diff (4)	t (5)
Efficiency	CIT		.914	.701	.213	3.99**
	PCC	1.00	.696	.170	.526	2.60**
	ALL		.795	.452	.342	3.19**
Bais	CIT		−3.51	−12.52	9.01	4.52**
	PCC	0	−6.75	−12.22	5.47	2.08**
	ALL		−5.28	−12.38	7.10	4.29**
Breakdowns	CIT		.072	.247	.175	3.16**
	PCC	0	.240	.453	.214	3.03**
	ALL		.164	.344	.180	3.92**

* indicates significant at level .05, and ** indicates significant at level .01

Table 6. Distribution of bias (r) for full and private information treatments (only observations with $x^* \leq 50$). Top rows of table represents all data, bottom is data where agreement was reached.

		n		Mean		StdDev				
	Pool	Full (1)	Priv (2)	Full (3)	Priv (4)	Full (5)	Priv (6)	t (7)	F (8)	KS (9)
ALL	CIT	83	85	−.351	−12.52	10.9	14.6	4.51**	1.79**	0.504**
	PCC	100	75	−6.75	−12.22	14.9	20.0	2.08*	1.79**	0.313**
	ALL	183	160	−5.27	−12.38	13.3	17.3	4.29**	1.69**	0.381**
Agreement	CIT	77	64	−0.73	−6.22	3.8	9.3	4.71**	5.98**	0.443**
	PCC	76	41	−0.04	−1.00	6.7	14.8	−0.53	4.87**	0.249**
	ALL	153	105	−0.39	−3.40	5.4	12.2	2.69**	5.06**	0.325**

* indicates significant at level .05, and ** indicates significant at level .01.

By definition, truncation of the policy space must contribute to bias for cases when the efficient x^* is near the truncation point of $x = 100$. Nevertheless, the results we report above appear to be robust, and in fact even strengthen when we eliminate all observations that could be subject to the truncation bias. Therefore we discard truncation as an explanation for our findings.

7. Summary

In summary, in our bargaining experiments we find significant differences between the complete and incomplete information treatments. On the three criteria of (A) efficiency, (B) allocative neutrality, and (C) bargaining breakdown, the predictions of the Coase

Theorem fare significantly worse in the case of private information than in the case of complete information. For the case of private information, we can reject the prediction of allocative neutrality of the Coase theorem in favor of bias towards the status quo predicted by the generalized Myerson–Satterthwaite theorem.

We also find significant subject pool differences, with higher efficiency, fewer bargaining breakdowns, but more bias in the CIT pool than in the PCC pool. We attribute this to the fact that the Caltech subjects are on average more analytically inclined and comfortable with computers and hence understand the experiment more easily than the PCC subjects. The fact that higher efficiency and fewer bargaining breakdowns does not translate into less bias in the incomplete information setting suggests that unlike transaction costs, the strategic value and use of private information is not something that will disappear with more experienced or expert subjects. Rather, expert subjects are more likely to understand the strategic value of private information, and hence come closer to the game theoretic predictions of Myerson–Satterthwaite.

We conclude that private information has a major impact in diminishing the predictive validity of the Coase theorem. In comparison, the generalized Myerson–Satterthwaite theorem predicts substantially better than the Coase theorem when there is private information, and with more expert subjects, these differences become attenuated.

Acknowledgments

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Appendix: Experiment instructions

This is an experiment in decision making, and you will be paid for your participation *in cash*, at the end of the experiment. Different subjects may earn different amounts. What *you* earn depends partly on your decisions, partly on the decisions of others, and partly on chance. No other person will be told how much cash you earned in the experiment. You need not tell any other participant how much you earned.

The entire experiment will take place through computer terminals, and all interaction between you will take place through the computers. It is important that during the experiment you communicate only through the computers. If you disobey the rules, we will have to ask you to leave the experiment.

We will start with an instruction period during which you will be given a description of the experiment and shown how to use the computers. It is important that you listen carefully. If you have any questions during the instruction period, raise your hand and your question will be answered so everyone can hear.

Start Computer Session:

During the computer instruction session, we will teach you how to use the computer by going through a practice match. During the computer instruction session, *do not hit any keys* *or touch the mouse until you are told to do so*, and when you are told to enter information, *type exactly what you are told to type.* You are not paid for the practice match.

[START PROGRAM]

To start the program, double click on the icon labeled “Experiment xx”. When the computer prompts you for your social security number, please enter your social security number. If you are not yet registered in the data base, the computer will prompt you for your full name and address. Please fill this out.

[WAIT FOR SUBJECTS TO ENTER NAMES]

You now see the experiment screen. DO NOT CLICK THE MOUSE OR PRESS ANY KEYS until you are told to do so.

The subjects in this experiment are divided into two groups of equal numbers. The subjects in one group are labeled Red, and those in the other group are Blue. At the top of the screen you see your own subject number and color. Please write down this information on your record sheet. Your color will stay the same for the entire experiment. Please remember your color, because the instructions are slightly different for the Blue and the Red subjects.

What is a match?

The experiment consists of several matches. In each match, you will be matched with a different subject of the opposite color from yours. Thus, if your color is Blue, then you will be matched with a series of Red subjects. If your color is Red, you will be matched with a series of Blue subjects. The subject that you are matched with in the practice match appears on the top of your screen. During the practice session, you can see the subject you are matched with. During an actual match, this will not be displayed. We will now start begin a practice match.

[START PRACTICE MATCH]

You now see on your screen a series of curves. Ten curves are red. All but one of these are dotted, and one is solid. Ten are Blue, all but one of these is dotted, and one is solid. The solid curve of your own color is used to determine your payoff from the experiment. The dotted curves will be explained later. They represent possible curves that may be used in other matches.

[VERIFY MATCHING]

During each match, you and the subject you are matched with have a fixed amount of time to select a point on your computer screen. When the match starts, the clock will start ticking, and the amount of time remaining will appear in the box labeled “Time” on the right hand side of the display.

Your Payoffs:

If you are a Red subject, then your payoff from the experiment is the vertical distance that the agreed on point is *above* the solid Red curve. If you are a Blue subject, then your payoff from the experiment is the vertical distance that the agreed on point is *below* the solid Blue curve.

[ILLUSTRATE WITH OVERHEAD]

Now move your mouse around the screen, *without clicking the mouse* button. Stop moving the mouse at any point in the diagram. Notice that the position of the mouse pointer is given in the third row of the upper box labeled "Cursor.' The horizontal and vertical positions are represented by x and y and are given in the boxes labeled x and y. The box labeled "Additional Value" shows you the value of the point. This is the payoff you would get if this location became the agreed-upon point. Now move the mouse around the diagram and make sure you can find the region where your value is greater than zero, where it is zero, and where it is negative. If you are a red subject, then the value will be less than zero if you are below your curve (the solid red curve), zero if you are on the curve, and positive if you are above the curve. If you are a blue subject, then the value will be less than zero if you are above your curve (the solid blue curve), zero if you are on the curve, and greater than zero if you are below the blue curve.

The row labeled "Status Quo" shows you the position of the current agreement. At the beginning of each match, the Status Quo is at the point $x = 0$ and $y = 0$. It is marked on the graph with a yellow dot at the lower left corner. Since both the Red and Blue curves pass through this point, this has a value of 0 to each subject.

[HAND OUT RECORD SHEETS, START CLOCK]

We have now started the match, and you notice that the clock has started ticking down. In the practice session, the clock starts at 20 minutes. In the actual experiment it will be less.

Making Offers:

Next, we will see how to make an offer. First, Red subjects will make an offer while Blue subjects just listen. If you are a Red subject, move the mouse to approximately (80,60) and click the mouse on this point (don't worry if you are not right on the point). You will see a red dot at this point on your screen. You have just made an offer of this point to the Blue subject you are matched with. If you are the Blue subject matched with Red, you will see Red's offer as a Red dot on your screen. [NOTE: experimenter should have subjects do this at different times to illustrate who is matched with whom during this process.]

[DEMO THE MATCHING WITH SELECTED SUBJECTS]

If you are a Red subject, notice that the row labeled "Your Last Offer" now records the position and additional value to you of the offer you just made. If you are a Blue subject, you will see that the row labeled "Other's Last Offer' now records the offer of the red subject, along with its value to you. The "Additional Value" is the vertical distance between your curve and the other's offer, and represents the value to you of that point if this is the final point agreed to in the match.

Now, Blue subjects will make an offer while Red subjects just listen. If you are a Blue subject, move the mouse to approximately (32,10) and click the mouse on this point (don't worry if you are not right on the point). You will see a blue dot at this point on your screen. You have just made an offer of this point to the Red subject you are matched with. If you are the Red subject matched with Blue, you will see Blue's offer as a blue dot on your screen. If you are a Blue subject, notice that the row labeled "Your Last Offer" now records the position and additional value to you of the offer you just made. If you are a Red subject, you will see that the row labeled "Others Last Offer" now records the offer of the Blue subject, along with its value to you. The "Additional Value" is the vertical distance between your curve and the other's offer, and represents the value to you of that point if this is the final point agreed to in the match.

At any time until time runs out, either you or the other subject can make a new offer whenever you want. Each new offer you make replaces your previous offer, becoming your current offer. Your current offer is available for the other subject to accept until you replace it with a new offer. The other subject can make offers in the same way. To illustrate this, everyone now click on some point in your diagram on the screen (choose any point you want to). Wait for a few seconds and click on some other point. You will see that your latest and current offer appears as a new solid dot, and your previous offers become circles. Also, whenever you get a new offer from the other subject it becomes a solid dot, and the old offer becomes an empty circle. You can make an offer whenever you want. You do not have to wait for the other subject to make an offer for you to make a new one of your own.

Now click on three more points and make three more offers. You will see that when you make your sixth offer, your first one disappears from the screen. To keep things from getting too cluttered, only the five most recent offers are recorded on the screen.

Accepting an offer:

Next, we see how to accept an offer. First, all Blue subjects please make an offer at the point $x = 10$, $y = 20$.

[WAIT UNTIL ALL SUBJECTS ARE DONE]

If you are a Red subject move your mouse right on top of Blue's offer. When you hit the "hot spot" of the offer, a message will come on at the bottom of the screen, saying "Click to accept." Red subjects, click your mouse while this message is on. Red subjects have just accepted Blue's offer.

When an offer has been accepted, this then becomes the new status quo. Note that now the row labeled "Status Quo Value" shows the point that was just agreed to (20, 10) with a value of 19.70 if you are the Red subject, and -4.80 if you are the Blue subject. Your screen is now frozen until time has run out, and this is the end of the match.

In the actual experiment, the above process will continue until the time runs out. When the clock runs to 0, the match ends, and the outcome will be the current status quo agreement. If no agreement has been reached, the status quo will be at the original status quo, of $x = 0$, $y = 0$, which gives a payoff of zero to both subjects.

[END FIRST PRACTICE MATCH]

This concludes the first practice match. Write your payoff from the practice match on your Record Sheet.

Recall that in the first match, there were ten different dotted curves for each color. These represent different curves that might be selected in a match.

[ILLUSTRATE WITH OVERHEAD]

In the second practice match, you will have different curves from the first match, and also each subject may have a different curve from other subjects of the same color. During the experiment, for each new match, a new curve will be selected for each subject. This is done randomly by the computer, and for each subject, each of the ten curves can be selected with equal likelihood.

[START SECOND PRACTICE MATCH]

We have now started the second practice match. Note that you have been matched with a new subject of the opposite color. During this match, please practice making proposals, but *do not accept any offers* of the other subject until you are told to do so.

[DEMO HOW MATCHING HAS CHANGED]

I now want the Blue subjects to see how to accept an offer. Will the Red subjects now please make an offer at $x = 45$, $y = 30$.

[WAIT UNTIL ALL SUBJECTS ARE DONE]

Will all of the Blue subjects now move your mouse right on top of Red's offer. When you hit the "hot spot" of the offer, a message will come on at the bottom of the screen, saying "Click to accept." Blue subjects click your mouse while this message is on. Blue subjects have just accepted Red's offer.

[WAIT FOR MATCH TO CONCLUDE]

This concludes the second practice match. Please record your payoff from the second practice match.

Add the payoffs from the two practice matches and multiply your payoff from the practice match by the exchange rate, and enter this on your record sheet. You are not paid for the practice match, but if this were the actual experiment, this is the amount that you would be paid for this match.

ANY QUESTIONS?

[GIVE AND CORRECT QUIZ]

The actual experiment will consist of a number of matches similar to the practice match. In each match, you will be matched with a new subject of the opposite color of yours. During the actual experiment, the curves on your screen will be different in each match, and possibly different from the ones in the practice match. The amount of time for the actual matches will be 3 minutes.

At the end of the experiment, you will add up all your payoffs, except for the practice match. You will then convert your total payoff into your dollar earnings by multiplying your total payoff by the conversion factor. Add the participation fee to this amount to get the total amount that you will be paid for the experiment.

ANY QUESTIONS?

We are ready to begin the experiment. Remember each match is three minutes long, and the clock will count the remaining time for you. From now on, everything you do counts for real money. Remember that you will lose money if your payoff is negative in any match. So be careful what offers you make and accept.

[ANY QUESTIONS?]

[BEGIN EXPERIMENT]

[READ AFTER MATCH 4]

For this part of the experiment, you will have less information. You will still know your own curve, but you will not know the other subject's curve. On your screen you will see your own curve, as before, as a solid curve. But instead of seeing the other's curve, you will only see the ten possibilities it might be. Each possibility is shown as a dotted curve, and each of these dotted curves has the same probability of being the actual one.

Also on your screen you will see, along with your actual curve, the nine other possibilities it might have been as dotted curves. The other subject will know that one of your ten curves is the actual one, but will not know which of the ten it is.

[READ AFTER MATCH 12]

The last four matches will be exactly like the first four. You will now see both your own and the other subject's curve.

Notes

1. Coase (1990) apparently intended his theorem to be applied to environments with private information. He stated his theorem without restriction to complete information, and his applications are for cases of private information. In his example of the rancher and the farmer, it appears that neither party knows the other's cost or value (pp. 97–102); in his examples of actual legal cases, private information is the only plausible assumption (pp. 104–113); in his argument against Samuelson's claim of bargaining indeterminacy when there is private information he argues for an efficient bargaining outcome for the same information environment (pp. 160–163); and his argument against Pigovian taxes takes place in an environment of private information, where he argues that in many cases direct bargaining will be more efficient than trying to overcome the information requirements of Pigovian taxes (pp. 182–184).
2. Fudenberg and Tirole (1991, p. 279, see also p. 245) point out the conflict.
3. There are several differences between the Hoffman–Spitzer experiment and ours which may explain the difference in findings. In the Hoffman–Spitzer experiment, bargaining was face to face. The experimental subjects were explicitly allowed to reveal their private information and verify it by showing their worksheets to each other during the experiment if they so chose. Over half of the subjects chose to do so [personal communication with Matthew Spitzer (6/6/97)]. In our experiments, to control information flows and keep the complete and incomplete information treatments separate, communication was done through computers. In the Hoffman–Spitzer designs, there were seven or eight possible choices for the amount of harm ("activity level"); in ours there were 101 possible choices for the amount. Thus, the task of finding the efficient level, when information is private, was probably more difficult in our design. Finally, in the Hoffman and Spitzer experiments, there was unlimited time for bargaining, while we imposed time limits.
4. William Samuelson (1984) has pointed out the parallel between the Coase theorem and cooperative game theory.
5. He defined transactions costs as the costs to "discover who it is that one wishes to deal with, to inform people that one wishes to deal and on what terms, to conduct negotiations leading up to a bargain, to draw up the contract, to undertake the inspection needed to make sure that the terms of the contract are being observed, and so on." (Coase 1960, cited from Coase 1990, p. 114)
6. In the previous version of this paper, we reported on different data from two experiments run with 26 Caltech subjects. While conducting additional data analysis requested by the referee, we discovered that due to computer problems we were not able to recover the raw data from these experiments. Due to these problems, and to satisfy ourselves on other questions raised by the referees, we completely re-ran the experiments with a new and larger subject pool. Those are the experiments now reported in this paper. The conclusions based on the new data are essentially the same as those reported earlier.
7. In the third experiment, on match 13 one subject's computer crashed, and could not be restarted into the experiment. The data for the matches including that subject were deleted, and one additional complete information session was conducted in that experiment to compensate for the lost data. This accounts for the fact that there are 94 ($11 \times 4 + 10 \times 5$) full information matches in that experiment rather than 88.
8. The prediction of no breakdowns, although an immediate consequence of the efficiency claim, is less discussed in the Coasian literature than the claim of allocative neutrality with respect to rights assignments, even though the neutrality claim is more delicate since it requires quasi-linearity. In Coase's "The Problem of Social Cost" we find eight explicit claims that the amount of harm will be the same no matter what is the initial allocation of rights, and only two claims that there will be no bargaining breakdowns, and these latter statements are indirect. Coase writes "such a rearrangement of rights will always take place if it would lead to an increase in the value of production." (See Coase 1990, p. 114) Thus he indirectly claims that the disagreement point will be avoided when it is efficient to do so. In bargaining between firms Coase uses efficiency and maximum value of production synonymously. On p. 115 he restates this claim with the implication that there will never be bargaining breakdown. But later, in his "Notes on the Problem of Social Cost," while criticizing Samuelson's

view that bilateral bargaining can lead to indeterminacy and inefficiency, Coase softens his implied claim of no breakdowns by writing it is "impossible to argue that two individuals negotiating an exchange must end up on the contract curve, even in a world of zero transactions costs. ... However, there is good reason to suppose that the proportion of cases in which no agreement is reached will be small." (See Coase 1990, pp. 101, 102, 103, 104, 106, 108 and 110.)

9. These numerical examples suggest that generalized versions of the Myerson–Satterthwaite theorem might provide a theory of strikes.
10. The low efficiency in the PCC subject pool is due in part to a large number of observations in which one subject agreed to a payoff less than zero. There were 11 such observations in the PCC subject pool as opposed to 2 in the CIT pool. When these observations are removed, the efficiencies for the PCC pool are 78.6 and 68.2 for the full and private information treatments.
11. We use the Kolmogorov–Smirnov test rather than a χ^2 test because the number of observations in each category is not large enough for a χ^2 test.

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